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TILLAGE SYSTEMS FOR COTTON—

A Comparison in the U.S. Western Region

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Cooperative regional research in Arizona, California, and New Mexico from 1968 to 1971 was undertaken to determine the potential for both increased cotton yield and reduced tillage expenditures through tillage practices that allowed improved physical soil characteristics. Significant differences among the various tillage treatments were, for the most part, confined to the Las Cruces station in New Mexico, where in 1970 and 1971, both crop and soil showed major effects from serious limitations of water infiltration. Crop and soil performed as well with the chisel-list tillage treatments (in all cases) and the minimum tillage treatment (in most cases) as with the more intensive treatments of conventional tillage and rotary tillage. Financial savings connected with substituting chisel-list or minimum tillage for conventional tillage were about 8 and 14 dollars per acre, respectively. When applied to the cotton acreage in the U. S. Western Region, currently being cropped using conventional tillage, these figures represent a major potential economy.

January, 1975

Technical Committee Western Regional Research—Project W-99

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Under procedure for cooperative publications, this regional report becomes in effect an identical publication of each of the cooperating agencies, and is mailed under the frank and indicia of each.

TILLAGE SYSTEMS FOR COTTON— A COMPARISON IN THE U. S. WESTERN REGION[1, 2]

Before 1968, researchers in Arizona, California, and New Mexico were investigating independently the interrelationships among tillage methods, soil compaction and cotton productivity (Abernathy, 1970; Carter *et al.*, 1965; Carter and Colwick, 1971; and Le Pori and Stapleton, 1967). This research had indicated a potential for both increased cotton yield through tillage practices that allowed improved soil penetrability and for reduced tillage energy and costs.

Because both research objectives and cotton field conditions among these three states are similar, a coordinated research effort was undertaken from 1968 to 1971 to determine for the range of soil and climatic conditions found in the cotton-producing areas of the three states: (1) the relative effects of conventional tillage practices that involve intensive soil manipulation, and (2) the effects of such experimental tillage practices as minimum tillage, rotary tillage, and precision tillage (subsoiling under the plant row before planting) on cotton plant growth and yield, as well as on soil resistance to penetration.

Individual stations gathered information on effects of tillage on seedling emergence, root development, water infiltration rate, soil moisture content, seedbed alkalinity, seedbed penetration resistance, and soil dry-bulk density.

Test locations, climate, and soil types

Experimental trials were carried out on four research stations. These included two locations in Arizona, the Safford Experiment Station, and the Marana Experiment Station of the University of Arizona College of Agriculture. At New Mexico the experiment was conducted on the New Mexico State University Experiment Station Farm at Las Cruces. In California the plots were located on the U. S. Cotton Research Station, Shafter, administered by the Agricultural Research Service. The four stations will be, respectively, designated as Safford, Marana, Las Cruces, and Shafter. The climatic conditions for the research stations are given in table 1.

During the course of the experiment (1968–1971), variations of weather conditions which would have affected the cotton crop were within the range of expected values, except for the Marana Station, which had 9.45 inches of rain in August, 1971, followed by 2.25 inches and 2.14 inches, respectively, in September and October of that year. The high incidence of boll rot in 1971 was blamed on this high rainfall.

The soils on which the experimental plots were established are described in table 2. The soils of the Las Cruces station suffered from an unusually low water

[1] Submitted for publication September 10, 1973.

[2] The USDA Agricultural Research Service and agricultural experiment stations of the University of Arizona, the University of California, and New Mexico State University have cooperated on regional research on cotton mechanization for 20 years. Project W-24, "The Improvement of Mechanized Production and Harvesting of Irrigated Cotton in the Arid and Semiarid West," started in July, 1953, and continued until June, 1967. At that time, the need to focus research efforts on the single common problem of obtaining the proper seed environment for cotton germination resulted in Project W-99—"Application of Tillage Equipment Systems to Improve Soil Environment for Cotton"—which is reported here.

TABLE 1

HISTORICAL AVERAGE CLIMATIC CONDITIONS AT FOUR COTTON RESEARCH STATIONS IN ARIZONA, NEW MEXICO, AND CALIFORNIA

Elevation		Mean annual rainfall		Mean minimum and maximum temperatures (degrees F.) in:							
				March		June		September		December	
ft.	m	in.	mm	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
Safford											
2,900	882	8.54	217	35.7	68.0	58.2	97.3	57.8	91.8	29.5	60.0
Marana											
1,900	578	11.0	282	42.4	71.6	64.8	100.3	65.3	93.7	37.8	64.8
Las Cruces											
4,000	1,220	8.32	211	34.2	68.7	58.8	93.9	56.1	86.7	26.1	57.3
Shafter											
600	183	6.14	156	42.3	68.5	59.2	92.2	57.2	90.3	36.3	56.3

infiltration rate for the irrigation water used. This problem was particularly acute during the last two years of the experiment.

Tillage treatments

Table 3 shows the schedule of treatment applications for the four stations during the four-year period. Each treatment was applied with four replicated plots at all four locations. Initially, treatments were randomly assigned to experimental plots. This same assignment was then maintained throughout the four years, so that the cumulative effects on the soil of any one treatment could be ascertained.

Minimum tillage. Cotton stalks were broken up by a horizontal stalk chopper, except at the Shafter station, where a root- and stalk-shredding machine was used. The root and stalk machine had a horizontal blade at furrow depth to loosen roots, which were subsequently shredded by the machine. Tillage, then, consisted of operating a lister (middle-buster) in the existing furrows to reform the old beds. This was followed by a planting sequence which was standard for all treatments at a given station, but which varied from station to station.

Conventional tillage. Treatment consisted of the following sequence:

a) one or two passes with a light disc harrow;

b) moldboard plowing with a 14- or 16-inch plow to a depth of 10 to 12 inches (plow operated in the direction of the rows);

c) one or two passes with a heavy disc harrow;

d) (at some stations smoothing was done with a drag float);

e) a lister used to form beds;

f) application of the planting sequence.

Rotary tillage. The treatment consisted of the following sequence:

a) up to two passes with a light disc harrow;

b) one rotary tiller pass to a depth of 8 inches (Las Cruces) or 10 inches (Shafter);

c) one pass (if needed) with a heavy disc harrow;

d) a lister used to form beds;

e) application of the planting sequence.

Chisel-list (precision tillage). A combination tool was used incorporating chisels attached to the forward part of the implement frame and listers attached to the rear (fig. 1). The chisels were laterally positioned to operate in the center of

TABLE 2

PHYSICAL SOIL ANALYSES AT FOUR COTTON RESEARCH STATIONS

Station	Name of soil	Depth		Particle size analysis (per cent by weight)								Moisture content (per cent dry basis)	
		ft.	mm	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Total clay	Fine clay	Field capacity	Wilting point
Safford	Pima clay loam	0–1	0–25	1.1	3.0	4.4	12.0	9.4	38.1	32.0	28.0	27.38	14.19
	Pima silt loam	1–2	25–51	1.4	5.0	7.2	3.6	8.6	62.2	12.6	11.4	16.23	7.44
Marana	Gila clay loam	0–1	0–25	0.3	0.7	1.6	11.0	12.8	39.6	34.0	28.0	26.51	14.60
	Gila silty clay loam	1–2	25–51	1.3	1.5	2.0	9.5	1.9	53.8	30.0	26.0	27.51	14.19
Las Cruses	Belen loam (A)*	0–1	0–25	0.3	0.2	0.8	3.4	8.3	42.8	20.0	24.0	29.44	17.00
	Belen silty clay loam (A)	1–2	25–51	0.1	0.3	1.3	3.3	6.6	49.2	35.0	4.0	33.14	20.35
	Belen loam (B)*	0–1	0–25	0.1	0.2	0.4	2.9	10.3	47.0	6.0	33.0	28.40	16.85
	Belen silt loam (B)	1–2	25–51	0.1	0.2	0.6	2.7	6.3	71.5	2.5	16.0	30.80	18.35
Shafter	Hesperia sandy loam	0–1	0–25	14.0	13.6	10.6	19.0	13.6	18.6	10.4	10.0	11.25	4.87
	Hesperia sandy loam	1–2	25–51	13.6	14.1	10.6	18.0	13.6	20.0	10.2	10.0	10.85	4.70

* Soil conditions were varied at Las Cruces. Soil is generally classified as Belen clay of which the "A" soil is typical. About one-fourth of replications 1 and 4 were on the "B" soil which appeared to have coarser texture and better physical conditions than soil "A."

TABLE 3

TILLAGE TREATMENTS USED IN FIELD TRIALS AT THE FOUR STATIONS (1968 to 1971)

Tillage treatment	Station															
	Safford				Marana				Las Cruces				Shafter			
	Year, 19–				Year, 19–				Year, 19–				Year, 19–			
	68	69	70	71	68	69	70	71	68	69	70	71	68	69	70	71
Minimum tillage		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Conventional tillage		X	X	X		X	X	X	..	..	..	..	X	X	X	X
Rotary tillage		..	..	..		..	..	..	X	X	X	X	X	X	X	X
Chisel-list		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Chisel-list (beds moved)		X	X	X		X	X	X	X	X	X	X	X	X	X	X
Shallow chisel-list		X	X	X		X	X	X	..	..	..	..	..	..	..	..

the previous beds, and the listers positioned to operate in the previous furrows and to reconstruct the beds in their previous position. The chisels were operated 18 to 22 inches below the original soil surface. This operation was then followed by the planting sequence. The somewhat cloddy bed condition produced is illustrated in figure 2.

Chisel-list (precision tillage) with beds moved 20 inches. This treatment was the same as the treatment just described, except that the chisels were laterally positioned to operate in the furrows of the previous crop, and the listers were positioned to operate in the middle of the beds of the previous crop. Thus, the new beds were formed over the channel cut by the chisels, but these beds were laterally displaced 20 inches (half the conventional bed spacing) from the position of the beds for the previous crop.

Each treatment offered a different advantage. The conventional tillage method was, in some cases, related to top yield levels (Abernathy, 1970). Minimum tillage offered opportunities to save both money and energy (Abernathy, 1970; Le Pori and Stapleton, 1967). Rotary tillage efficiently transmitted a large amount of tillage energy to the soil with minimum traction requirements. Also, all rotary tillage requirements could be accomplished with a single operation. Rotary tillage also made possible the practice of preserving fixed traffic lanes in a given field to minimize the proportion of field area subjected to compacting wheel traffic—whereas the plow-disc tillage method tends to remove visible marks of previous traffic lanes, making the lines difficult to re-establish. Chisel-list tillage offered special yield advantages on certain soils (Carter *et al.*, 1965), potentials for reduced costs and energy inputs (Abernathy, 1970; and Le Pori and Stapleton, 1967), and, along with minimum tillage, the possibility of favorably influencing plant growth through reduced soil compaction (Carter *et al.*, 1965; Carter and Tavernetti, 1968; Carter, 1969; and Carter and Colwick, 1971).

The costs of each set of tillage operations for each state are estimated in table 4. They are based on custom-rate data, and include all operations through bed formation, but they exclude stalk disposal.

Production practices

Planting operations varied at each of the stations according to the management system and past experience with the individual fields. Preplant irrigations were applied at the Shafter, Las Cruces, and Marana stations. At the Safford station, irrigation was sometimes applied after planting. At Shafter, a nematocide was applied (two shanks, 14 inches apart, centered on the bed and operating at a 12-inch depth) beween the pre-plant irrigation and planting.

A preplant herbicide was applied at some stations; at others, a rolling culti-

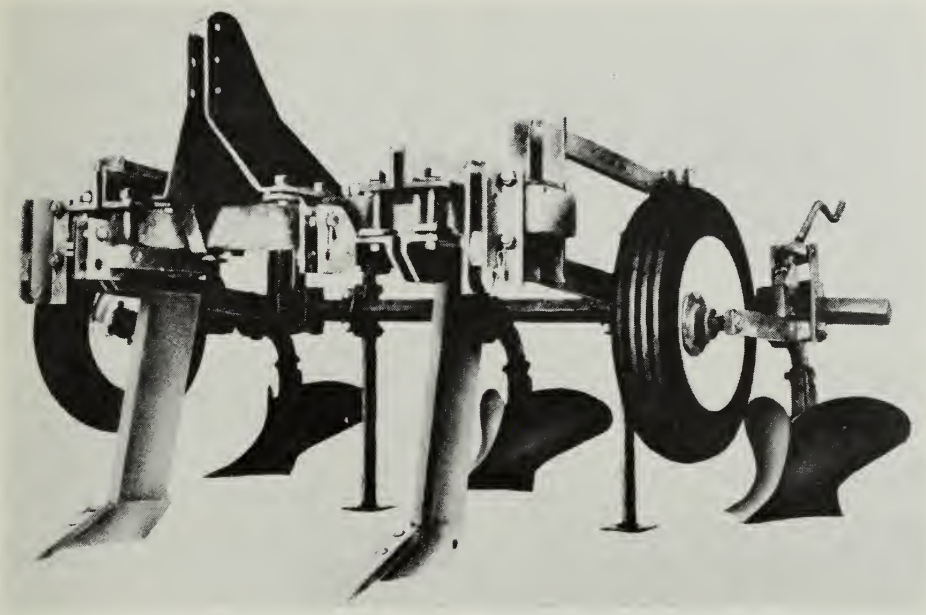

Fig. 1. Equipment used for chisel-list tillage. When beds are moved, chisels operate in furrows, and listers move soil from old beds to form new beds over the old furrows. When beds are not moved, chisels are operated in the middle of beds.

Fig. 2. Typical listed ridges after chisel-listing. Note rough, cloddy condition of soil surface. Subsequent irrigation will cause disintegration of many of these clods.

vator was used to incorporate a post-planting herbicide. Mechanical cultivation was used as needed at still others. Defoliant and insecticides, when needed, were applied by aircraft.

At the Shafter station, traffic was confined to alternate furrows, and the harvester used was equipped with a wide rear axle to avoid traffic in the furrow from which traffic was excluded. Generally, harvesting was delayed for once-over harvest, except at the Shafter station where two pickings were used.

The rotary tillage treatment was not applied at the Safford or Marana stations, but at these stations an additional chisel-list treatment was applied with chisels operating only 12 to 14 inches deep. The conventional tillage treatment was not applied at the Las Cruces station (see table 3).

Table 4
ESTIMATED OPERATION COSTS FOR DIFFERENT TILLAGE METHODS IN THREE STATES (1970)

Treatment	Cost (dollars per acre)			
	Arizona	California	New Mexico	Average
Minimum tillage	1.51	2.43	1.35	1.76
Conventional tillage	15.25	15.83	16.31	15.78
Rotary tillage	15.25*	19.28	9.45	14.66
Chisel-list	5.87	7.96	8.77	7.53

* Although rotary tillage was not used in the Arizona experiments, the expected custom rate for this operation is given here based on general cost information available for Arizona conditions.

Good agronomic cultural practices on the plots were subsequently used as directed by station field superintendents. Thus, decisions on when to irrigate, and the like, were not made according to specific criteria set up in advance for these tests.

Test parameters

Yield. The most important parameter of treatment results—total seed cotton yield—was measured at all stations for all years of treatment application. All yield results are presented in terms of bales (1550 lb. seed cotton) per acre. At the Shafter station, two pickings were usually made and results were totaled. In one year at the Shafter station—and generally at the Marana, Safford, and Las Cruces stations—harvest was delayed until late in the season, and only a single picking was used. Machine harvest was used in all cases.

Average penetrometer resistance. The penetrometer instruments used at each station are described in table 5.

The specifications in table 5 conform approximately to the American Society of Agricultural Engineers recommendations for soil cone penetrometers (ASAE, 1971). At all stations the penetrometers

Table 5
DESCRIPTIONS OF SOIL PENETROMETERS USED AT VARIOUS STATIONS

Station	Cone included angle	Cone base area	Cone material	Shaft diameter
	Degrees	*Sq. in.*		*Inches*
Safford	30	0.5	Tool steel surface hardened	1/2
Marana	30	0.5	Tool steel surface hardened	1/2
Las Cruces	30	0.2	Mild steel	7/16
Shafter	30	0.2	Mild steel case hardened surface ground	3/8

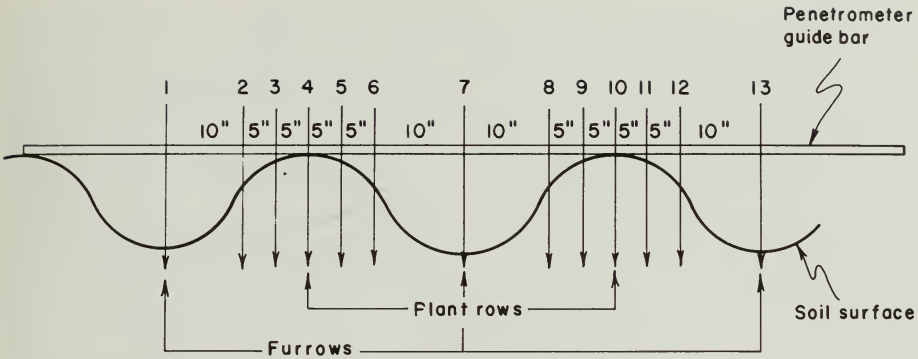

Fig. 3. Diagram showing number of penetrometer insertions, their depth, and distance apart—relative to beds and furrows.

were used after the first-crop irrigation when the soil was estimated to be uniformly at field capacity moisture content. Due to water infiltration problems this criterion possibly was not satisfied at the Las Cruces station during 1970 and 1971.

The penetrometer was pressed into the soil at 13 points across a two-row plot cross-section (fig. 3).

At the Safford and Marana stations, the penetrometer was pressed into the soil to a depth of 24 inches using a hydraulic ram mounted on a tractor. Force and depth measurements were transmitted to an x-y plotter, and data were

Fig. 4. Penetrometer and insertion apparatus. Note X-Y plotter on which penetrometer depth and resistance were simultaneously recorded.

transcribed from the curves plotted at intervals corresponding to 2-inch increment of depth (fig. 4).

At the Las Cruces station, the penetrometer was inserted by a hydraulic sampler to 32 inches, and a strip-chart recorder with a depth-actuated event marker was used to obtain penetrometer force readings at 4-inch depth intervals.

At the Shafter station hand insertion of a mechanically recording penetrometer was used. At points on the recorder chart where penetration resistance values reached 50, 100, 350 and 400 lbs. per sq. in., corresponding values of penetrometer depth were determined and transcribed.

Penetrometer readings were taken in all four years at the Las Cruces station, in all but 1968 at the Safford station, and in only 1970 and 1971 at the remaining stations.

In all cases, penetrometer resistance readings are presented in terms of pounds of resistance per square inch of penetrometer cone base area. Typical or average profiles of penetrometer resistance were developed at each station for each treatment. Each value then, is the average penetrometer resistance over the cross-sectional area of the profile sample.

Standard deviation of penetrometer resistance. Although profiles of penetrometer resistance were obtained with two different approaches, the basic data permitted determinations of penetrometer resistance readings (in pounds per square inch) at each of a set of uniformly distributed points throughout the soil profile. This permitted measurement of the extent of variation of the penetrometer resistance of individual points from the mean for the cross-section sampled.

This standard deviation parameter would be high if the profile consisted of some sections with very high resistance and some with very low resistance. If penetration resistance was nearly uniform throughout the cross-section, values of this standard deviation would be low.

Crop growth data. At the Shafter, Marana, and Safford stations, 25 plants were cut from each plot at approximately the first bloom stage, oven-dried, and the average grams of dry matter per plant determined. At the Las Cruces station, plant height data, at approximately the same stage of growth, were obtained.[3] On the basis of an empirical relationship between cotton plant height and dry weight,[4] height data was converted to grams of dry matter per plant.

All stations reported crop growth data for 1970 and 1971, while the Las Cruces station obtained data for 1968 and 1969 as well. The stage of plant development at which measurements were taken was not always consistent from year to year at a given station, or from station to station in a given year.

Chisel-resistance energy per unit distance. In late November, 1971, a specially equipped implement containing two chisels (fig. 5) was used in all plots at the Las Cruces, Shafter, and Safford stations. This chisel apparatus was able to measure the total draft energy required per 10 ft of travel while operating at a depth of 12 inches below the bottom of the furrow. The chisels were operated in the center of the beds. Between 10 and 20 10-ft runs were made in each plot at an approximate forward speed of 1.5 miles per hour. The energy per 10 ft when divided by 10 ft was then equal to the average draft of the implement.

This average draft (lb) was the measurement used for this study. Since the same instrument was applied in all three states, soil resistance (under low mois-

[3] Ten consecutive plants were measured at each of six locations within each plot. The distance measured was that from the soil surface to the uppermost tip of each plant.

[4] The empirical relationship between cotton plant height and plant dry weight was determined from unpublished data obtained from Professor H. N. Stapleton, University of Arizona.

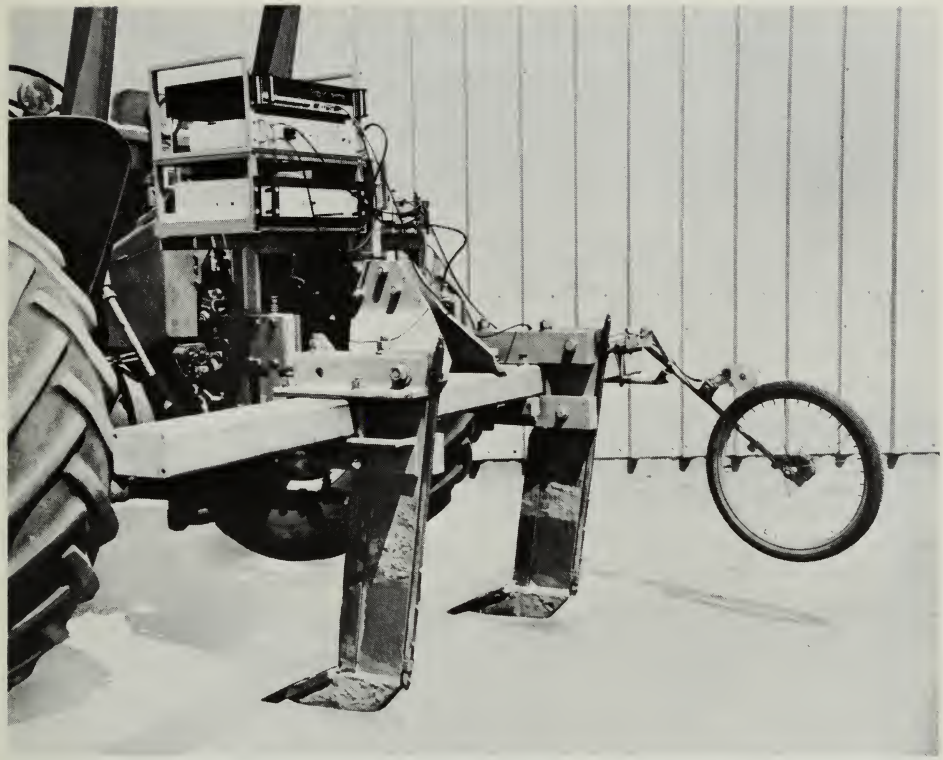

Fig. 5. Chisels instrumented for measurement of tillage resistance energy per unit of travel. Wheel shown measures travel distance. Energy consumed is electronically computed and summed for 10-ft. intervals.

ture content conditions) could be compared directly in all three locations.

Water infiltration rate. Water infiltration rates were measured at the Shafter and Las Cruces stations with a single-ring infiltrometer placed in the furrow. At Shafter, measurements were taken in the non-traffic furrow in 1968 and 1971, and in the traffic furrow in 1971. At Las Cruces, all furrows sustained traffic, and measurements were made in all four years. In all cases, the rates were determined after infiltration had been under way for some time. At Shafter, data were recorded after about 1 ft of water had passed through the infiltrometer. At Las Cruces, data were recorded four to seven days after the infiltrometer operation had begun. This greatly delayed measurement was due to the very low permeability of the soil. Even then, the rate of infiltration probably had not stabilized.

Seedling emergence. Approximately three weeks after planting, counts were made to determine stand density and seedling emergence. At the Safford and Marana stations, counts were made in two 13-ft sections from each end of the two center rows of each plot during the years 1970 and 1971. At the Las Cruces station, counts were made in random locations in each plot during all four years. Data are presented in terms of thousands of plants per acre.

These counts provided not only estimates of how tillage practices and soil conditions affected soil resistance to seedling emergence but also indications of the number of plants available for production of yield.

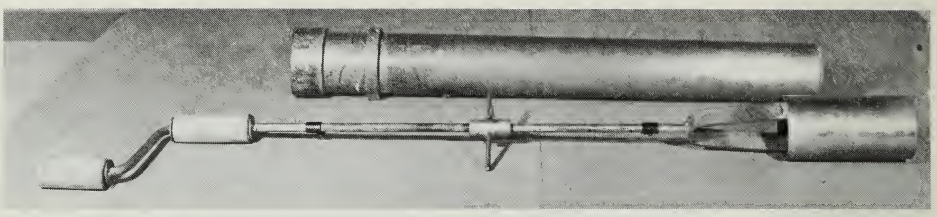

Fig. 6. Instrument for sampling soil bulk density. Above, 3½ in. diameter core tube, and below, close-fitting auger bucket. Adjustable cross-stop on auger handle is used to gage depth to which overburden is removed, and then depth to which sample is taken. Instrument was built especially for use in this study.

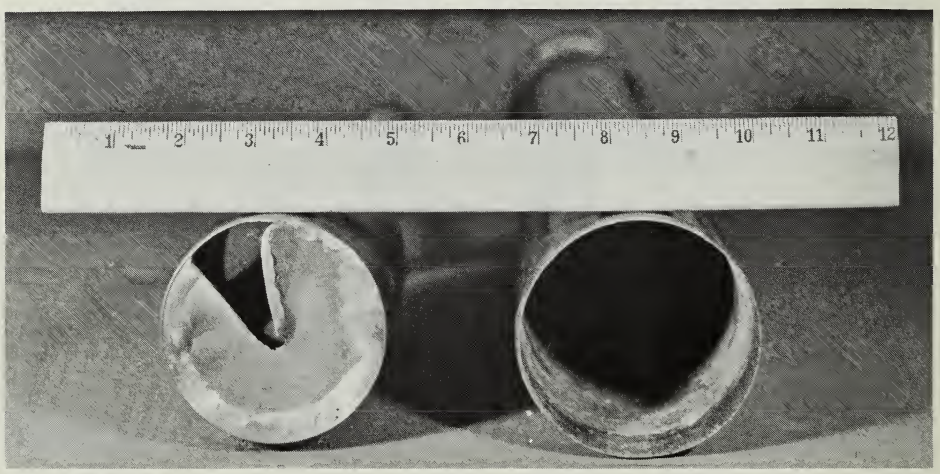

Fig. 7. End view of core tube and auger bucket of soil bulk density sampling tool.

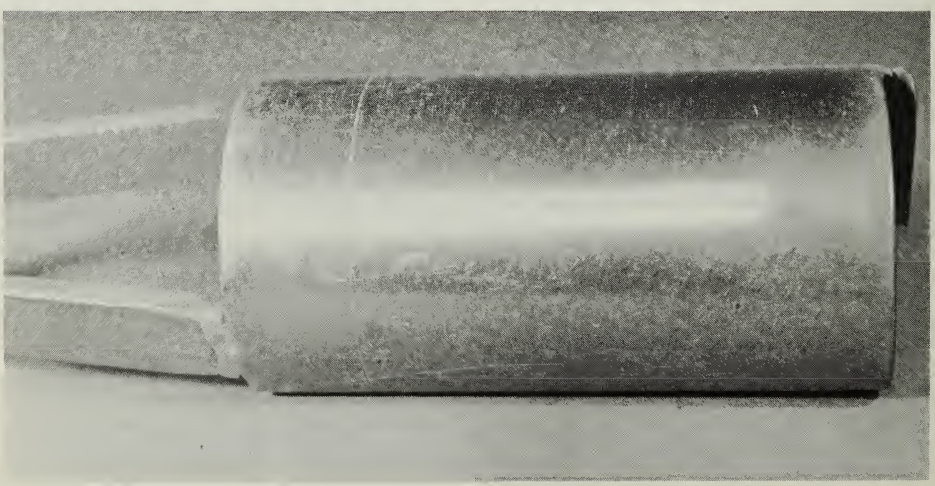

Fig. 8. Detail of cutting lip on auger bucket of soil bulk density sampling tool.

The preceding seven parameters were the only ones measured in more than one state. However, each station, acting individually, measured other soil or plant parameters.

At the Shafter station in 1971, soil dry-bulk density was measured in the top first and second feet of soil for both the traffic and nontraffic furrows. Using the unique instrument illustrated in figures 6, 7, and 8, the 3½-inch core tube was driven into the soil. Then, a close-fitting auger bucket was used to remove overburden to the desired sampling depth. The soil to the maximum sampling depth was then separately removed, dried, and weighed. Results are reported in grams per cubic centimeter.

At the Marana and Safford stations, data were collected in 1970 and 1971 on both tap root length and tap root development of the cotton plants. Tap root length (in inches) was noted on 10 mature plants per plot (four per plot in 1970) pulled from the field when the field was very wet. These same plants were also examined for the form of tap root development, with the percentage of normal specimens recorded. Abnormal root development was characterized by the absence of a tap root (a sprangle of roots instead of a single tap root) and roots showing crooks indicating that the tap root had been growing horizontally.

At the Las Cruces station, three sampling procedures were used to evaluate seedbed conditions for each of the four years:

First, multiple soil samples between the 1- and 3-inch depth were collected from each plot with a ¾-inch diameter tubular soil sampler. They were composited and dried to determine moisture content (per cent of dry matter weight). This same material was then made into a saturated soil paste, and the weight of total soluble salts as a per cent of the total dry matter weight was determined.

Second, a standard soil extract from soil samples from each plot was analyzed to determine its pH and per cent exchangeable sodium.

Third, soil resistance was measured with a special penetrometer consisting of a ¼-inch diameter steel rod with a conical point (30 degree included angle) on one end. Resistance to its insertion was measured using a strain-gauge transducer connected to a strip-chart recorder with marks made at the 0-, 1-, 2-, and 3-inch penetration depths. Average values of penetration resistance in the 0- to 1-inch, 1- to 2-inch, and 2- to 3-inch spans were determined in terms of grams (force) per square centimeter of penetrometer cross-sectional area (0.316 sq. cm). In 1968, data were obtained for only the 2- to 3-inch span. These values were believed to be related to the soil resistance that would be encountered by emerging seedlings.

At the Las Cruces station, one of the major problems in cotton culture was the low water infiltration rates. To determine the effects of the various tillage treatments on the amount of water that could be applied, measurements were made of the water applied during the first irrigation and of the total water applied on the crop. The time required to collect water in a 2-gallon sample from gated irrigation pipe serving each furrow was noted. Inches of water applied to each plot were calculated from this rate of flow and the total time of application.

Results

The design of this experiment permitted the combining of measurements and results for tillage treatments carried out at all four stations. Some tillage treatments and result measurements applied only to one or two stations where they were considered.

Throughout this report, the word "significant" will indicate a 5 per cent or less probability of error, and the words

TABLE 6

AVERAGE COTTON YIELDS AND THEIR STATISTICAL SIGNIFICANCE FOR THREE TILLAGE TREATMENTS COMMON TO ALL FOUR STATIONS (1969 to 1971)

Station	Av. yields* (bales/acre)† from following treatment:			Total average
	Minimum tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	
Las Cruces	0.946 b c	1.133 b b	1.310 b a	1.130 b
Safford	1.520 a a	1.602 a a	1.566 a a	1.563 a
Marana	1.656 a a	1.721 a a	1.607 a a	1.661 a
Shafter	1.588 a a	1.731 a a	1.658 a a	1.659 a
Average	1.427 b	1.544 a	1.535 a	1.502

* Within a block, values with same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.
† One bale = 1,550 lbs. of seed cotton.

TABLE 7

AVERAGE COTTON YIELDS AND THEIR STATISTICAL SIGNIFICANCE ON AN ANNUAL BASIS AS AFFECTED BY MINIMUM TILLAGE AND BOTH CHISEL-LIST TREATMENTS AT FOUR STATIONS (1969 to 1971)

Station	Av. yields* (bales/acre)† in:			Total average
	1969	1970	1971	
Las Cruces	1.611 c a	1.005 b b	0.772 c c	1.130 b
Safford	1.683 bc a	1.458 a b	1.548 a ab	1.563 a
Marana	2.169 a a	1.567 a b	1.247 b c	1.661 a
Shafter	1.906 b a	1.583 a b	1.488 ab c	1.659 a
Average	1.821 a	1.403 b	1.232 c	1.502

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.
† One bale = 1,550 lbs. of seed cotton.

"highly significant" will indicate a 1 per cent or less probability of error. Where other test levels are used, the probability of error will be stated.

General results for the region

Yield. Table 6 shows that among the three tillage treatments common to all four stations, the average yields with minimum tillage were significantly less than those with the chisel-list treatments. However, there was a significant difference (2.5 per cent level) among the yield responses at one station and those at

TABLE 8

AVERAGE COTTON YIELDS AND STATISTICAL SIGNIFICANCE AT TWO STATIONS WHERE ALL TREATMENTS EXCEPT CONVENTIONAL TILLAGE WERE USED DURING FOUR CONSECUTIVE YEARS (1968 to 1971)

Station	Av. cotton yields* (bales/acre)† from following treatment:				Average
	Minimum tillage	Rotary tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	
Las Cruces	1.138 b bc	1.039 b c	1.287 b ab	1.438 a a	1.223 b
Shafter	1.650 a a	1.796 a a	1.751 a a	1.681 a a	1.771 a
Average	1.394 b	1.417 b	1.519 ab	1.559 a	1.467

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

† One bale = 1,550 lbs. of seed cotton.

Note: The interaction between station and treatments was significant at the 1 per cent level, while the effect of treatments alone was significant at the 5 per cent level. Thus, despite the average values indicating a significantly lower yield with rotary tillage than with chisel-list tillage (beds moved), the reverse was true at the Shafter station—although the difference was not significant.

another. Table 6 also shows the average yield results with each treatment at each station. A multiple range test for significance of differences between values in this table showed that yield values with the three treatments at all but the Las Cruces station were not significantly different from each other. However, at the Las Cruces station, not only were the yield values significantly lower than those obtained with similar treatments at the other stations, but also the yields obtained with each of the treatments at Las Cruces were significantly different from each other. At Las Cruces, minimum tillage produced the lowest yield, while chisel-list (beds moved) produced the highest yield. Table 7 shows how average yield at each station varied from year to year and from station to station. These results indicate a trend in time toward lower average yields (for these three treatments) at all but the Safford station, where the more or less constant yield pattern was found different.

The Marana station had the highest average yields in 1969 and the next-to-lowest yields in 1971. The Safford station had the highest in 1971 and next-to-lowest in 1969. The relative yield levels obtained with each treatment did not change significantly from year to year.

Rotary tillage treatment was used only at the Shafter and Las Cruces stations. These stations also obtained yield data in 1968 as well as in the following three years. The combined data for these four treatments and four years at the two stations showed a significant difference among yields obtained with the four treatments. However, a highly significant difference occurred between the yield pattern of treatments obtained at one station and the yield pattern obtained at the other. Table 8 shows rotary tillage to be associated with the lowest yield at the Las Cruces station and the highest yield at the Shafter station, while the chisel-list (beds moved) treatment gave the highest yields at the Las Cruces station and the next-to-lowest yields at the Shafter station. Over the four-year period, there were highly significant differences in average yields (for the four treatments) from year to year, and the trends at each

TABLE 9

AVERAGE COTTON YIELDS AND THEIR STATISTICAL SIGNIFICANCE ON AN ANNUAL BASIS AT TWO STATIONS WHERE ALL TREATMENTS EXCEPT CONVENTIONAL TILLAGE WERE USED DURING FOUR CONSECUTIVE YEARS
(1968 to 1971)

Station	Av. yield* (bales/acre(† in:				Average
	1968	1969	1970	1971	
Las Cruces	1.742 a	1.552 b	0.923 b	0.685 b	1.223 b
	a	a	b	c	
Shafter	1.802 a	1.960 a	1.579 a	1.537 a	1.711 a
	a	a	b	b	
Average	1.772	1.756	1.251	1.111	1.467
	a	a	b	b	

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.
† One bale = 1,550 lbs. of seed cotton.

TABLE 10

AVERAGE COTTON YIELDS AND THEIR STATISTICAL SIGNIFICANCE AT THREE STATIONS WHERE ALL TREATMENTS EXCEPT ROTARY TILLAGE WERE USED DURING FOUR CONSECUTIVE YEARS
(1968 to 1971)

Station	Av. yield* (bales/acres) † from following treatments:				Average
	Minimum tillage	Conventional tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	
Safford	1.528 a	1.582 a	1.602 a	1.566 a	1.568 a
	a	a	a	a	
Marana	1.656 a	1.671 a	1.721 a	1.607 a	1.644 a
	a	a	a	a	
Shafter	1.588 a	1.526 a	1.731 a	1.658 a	1.626 a
	a	a	a	a	
Average	1.591	1.593	1.685	1.610	1.619
	a	a	a	a	

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.
† One bale = 1,550 lbs. of seed cotton.

station tended to be highly significantly different from each other.

Table 9 illustrates the general trend toward decline of yield averages with time. Also shown is the much more rapid decline of yield at the Las Cruces station than at the Shafter station.

Conventional tillage treatment was applied along with minimum tillage and two chisel-list treatments only at the Safford, Marana, and Shafter stations, where results for only the years 1969, 1970, and 1971 could be compared. Neither the tillage treatments nor the station location affected the results, and the patterns of yield response to tillage treatments were not significantly different from one station to another (table 10).

TABLE 11
AVERAGE COTTON YIELDS AND THEIR STATISTICAL SIGNIFICANCE ON AN ANNUAL BASIS AT THREE STATIONS WHERE ALL TREATMENTS EXCEPT ROTARY TILLAGE WERE USED
(1969 to 1971)

Station	Av. yield* (bales/acre) † in:			Average
	1969	1970	1971	
Safford	1.700 b a	1.447 a b	1.557 b ab	1.568 a
Marana	2.171 a a	1.572 a b	1.248 a c	1.664 a
Shafter	1.888 b a	1.483 a b	1.507 b b	1.626 a
Average	1.920 a	1.500 b	1.437 b	1.619

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.
† One bale = 1,550 lbs. of seed cotton.

For no apparent reason, yields during 1969 were a great deal higher than those during the other two years. However, the patterns of yield differences varied widely from year to year and station to station (table 11). Yields at the Safford and Shafter stations during 1971 were higher than, but not significantly different from yields at these stations during 1970. However at the Marana station, yields during 1971 were significantly lower than those during 1970.[5]

Average penetrometer resistance. For the three tillage treatments common to all four stations, no significant difference was found among average penetrometer resistance values related to any treatment, except with minimum tillage at the Las Cruces station. There, the penetration resistance values were significantly higher than for the other two treatments, and the values linked to the chisel-list (beds moved) treatment were significantly lower than for the other two treatments (table 12). Yield responses had approximately the same pattern of differences as did penetration resistance responses. When significant differences in both these measures occurred, as at Las Cruces, high yields were associated with law penetration resistances and *vice versa* (compare tables 6 and 12).

Penetration resistance was nearly ten times as high at the Las Cruces station as at Safford or Marana, and nearly five times as high as at Shafter—a highly significant difference (tables 12 and 13). The differences among values for the remaining three stations were generally not significant. At Las Cruces, penetration resistance values showed a significant increase from 1970 to 1971, while this phenomenon did not occur for the remaining three stations (table 13), and values decreased significantly from 1970 to 1971 at the Shafter station for all but the minimum tillage treatment. These changes from year to year could have been related in part to differences in soil moisture content at the time of taking penetrometer measurements.

Analysis of the data from all stations but Las Cruces (where conventional tillage was not used) permitted comparison

[5] In 1971, cold weather caused the initial planting of the crop on the Marana station to fail. Replanting occurred relatively late in the season (May 3).

TABLE 12

AVERAGE PENETROMETER RESISTANCE AND STATISTICAL SIGNIFICANCE FOR THREE TILLAGE TREATMENTS COMMON TO ALL FOUR STATIONS (1969 to 1971)

Station	Av. penetrometer resistance* (lb/sq. in.) with following treatment:			Average
	Minimum tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	
Las Cruces	1148.7 b c	1033.5 b b	960.2 b a	1047.5 c
Safford	135.1 a a	114.2 a a	127.1 a a	125.5 a
Marana	126.0 a a	118.2 a a	114.4 a a	119.5 a
Shafter	225.7 a a	212.2 a a	215.2 a a	217.7 b
Average	408.9 b	369.5 a	354.2 a	377.5

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

TABLE 13

AVERAGE PENETROMETER RESISTANCE AND STATISTICAL SIGNIFICANCE ON AN ANNUAL BASIS FOR MINIMUM TILLAGE AND CHISEL-LIST TREATMENTS AT ALL FOUR STATIONS (1970 to 1971)

Station	Av. penetrometer resistance* (lb/sq. in) in:		Average
	1970	1971	
Las Cruces	919.6 c a	1175.4 b b	1047.5 c
Safford	114.7 a a	136.3 a a	125.5 a
Marana	117.8 a a	121.3 a a	119.5 a
Shafter	242.5 b a	192.4 a a	217.7 b
Average	348.6 a	406.4 b	377.5

Note: The interraction between station location and years was significant at the 0.5 per cent level, while the effect of years alone was significant at the 2.5 per cent level. Thus, despite the average values indicating a significantly lower penetration resistance in 1970 than in 1971, the reverse was true at the Shafter station—although the difference was not significant.

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

of the effects of conventional tillage with those of the other treatments. In general, the only significant difference was that penetration resistance for the conventional tillage treatment at the Shafter station was higher than for other treatments at that station and higher than for the same treatment at other stations. This response parallels that of yields for a similar comparison (table 10), with

TABLE 14
STANDARD DEVIATION OF PENETROMETER RESISTANCE WITH THREE TILLAGE TREATMENTS COMMON TO ALL STATIONS
(1970 to 1971)

Station	Av. S.D. penetrometer resistance* (lb/sq. in.):
Las Cruces	715.6 b
Safford	71.7 a
Marana	60.5 a
Shafter	105.4 a

* Values with the same letters *to the right* are not significantly different from each other at the 5 per cent level.

lower (but not significantly lower) yields recorded at this station for this treatment than for other treatments or at other stations.

At Las Cruces, penetration resistance was highest for the rotary tillage treatment during three out of the four years (and next to highest during the remaining year), while yields were the lowest with this treatment for three out of four years and next to lowest during the remaining year (table 8). This phenomenon did not appear at Shafter where the rotary tillage treatment was also applied.

Standard deviation of penetration resistance. Analysis of data from the three tillage treatments common to all four stations indicated no significant differences in the standard deviation of penetration resistance due to differences in any experimental factor—with one exception: the values for the Las Cruces station were of approximately 10 times the magnitude of those at the other stations (table 14). If Las Cruces data are excluded from analysis, and data from the conventional tillage treatment at the remaining three stations included, the following significant differences were found:

1. Deviation values at Shafter were higher than those at the other two stations (table 15).

2. Deviation values for the two chisel-list treatments were lower than those for the conventional tillage treatment at Shafter and lower than those for both the conventional and minimum tillage treatments at the Safford station (table 15). The tendency for the chisel-list treatments to result in lower values than did the minimum and rotary tillage treatments was also observed at the Las Cruces station.

3. At the Shafter station values in 1971 were generally lower than those in

TABLE 15
STANDARD DEVIATION OF PENETROMETER RESISTANCE WITH STATISTICAL SIGNIFICANCE AT THREE STATIONS WHERE ALL TREATMENTS EXCEPT ROTARY TILLAGE WERE USED
(1970 to 1971)

Station	Av. S.D. penetrometer resistance*(lb/sq. in.) with following treatment:				Average
	Minimum tillage	Conventional tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	
Safford	77.39 b ab	83.61 b a	68.36 a b	69.34 a b	74.7 a
Marana	60.60 a a	57.36 a a	61.56 a a	59.30 a a	59.7 b
Shafter	106.56 c ab	133.76 c c	113.94 b a	95.70 b b	112.5 c
Average	81.5 b	91.6 a	81.2 b	74.8 b	82.2

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

TABLE 16
REGRESSION EQUATIONS RELATING COTTON YIELD (Y) AND PENETRATION RESISTANCE (X)
(1968 to 1971)

Station	Years	Equation	Correlation coefficient (r)
	Absolute values: Y (bales per acre), X (lb/sq. in.)		
Las Cruces	1968, '69, '70, '71	$Y = -0.0012X + 2.137$	0.825**
Marana	1970, '71	$Y = -0.00183X + 1.627$	0.0961 N.S.
Safford	1969, '70, '71	$Y = 0.003427X + 1.0684$	0.674**
Shafter	1970, '71	$Y = -0.000993X + 1.769$	0.290 N.S.
Normalized values $Y = \frac{Y \text{ (bales per acre)}}{Y \text{ average for station-year}}$, $X = \frac{X \text{ (lb per sq. in.)}}{X \text{ average for station-year}}$			
Las Cruces	1968, '69, '70, '71	$Y = -0.8465X + 1.8656$	0.5408**
Marana	1970, '71	$Y = -0.004X + 1.0033$	0.0038 N.S.
Safford	1969, '70, '71	$Y = 0.3038X + 0.6946$	0.4474**
Shafter	1970, '71	$Y = -0.15X + 1.15$	0.24 N.S.
All Stations	1970, '71	$Y = 0.449X + 1.4521$	0.3745**

** Indicates that the correlation coefficient (r) is highly significant. N.S. indicates lack of significance the correlation coefficient.

1970, while the reverse was true for the remaining two stations.

Relations between penetration resistance and yield. Initially, linear regression analyses were attempted to relate penetration resistance and yield (table 16).

Penetration resistance (and resulting regression parameters for absolute values) was probably affected by various states of soil moisture at various times at each station. For this reason, and to permit aggregation of data from all stations, both yield and penetration resistance values were normalized by dividing each individual value for each replicate of each treatment by the average value (of either yield or penetration resistance) obtained at the corresponding station in the corresponding year. The results of the regression analysis of these normalized values are also presented in table 16.

The results (of both normalized and absolute values) show that at the Las Cruces station there was a highly significant *negative* correlation between penetration resistance and yield. Similarly, there was a highly significant *positive* correlation between penetration resistance and yield at the Safford station. At the other two stations, the negative correlations found were nonsignificant. For the combination of data from all stations, a highly significant negative correlation was found.

To summarize, penetration resistance and yield cannot be related to conditions at more than one location.

Where negative correlation was found at the Las Cruces station, the high penetration resistance may have restricted root growth and plant development. Alternatively, low soil permeability to water may have resulted in reduced soil moisture contents, causing increased soil penetration resistance and, at the same time, reducing water availability for plant growth.

The correlation of high yields with high penetration resistance at the Safford station may have been due to increased soil densities resulting in improved seed-soil contact and improved soil-water transmission to the plant in early stages of growth—if soil was unusually loose or unconsolidated at planting time.

Development of crop plants. Because plots were sampled at stages of growth which varied slightly from year

TABLE 17

COMPARISON OF CHISEL RESISTANCE DATA AND STATISTICAL SIGNIFICANCE DATA FROM SAFFORD AND SHAFTER STATIONS (Nov., 1971)

Treatment	Chisel-resistance energy* (ft-lb/ft) at:		Average
	Safford	Shafter	
Minimum tillage	4842 c b	2902 a a	3872 a
Conventional tillage	3629 a a	3568 b a	3598 a
Chisel-list (beds not moved)	4356 b b	3116 a a	3736 a
Chisel-list (beds moved)	4856 c b	3093 a a	3974 a
Average	4421 a	3170 b	3795

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

to year at any given station and from station to station in any given year, major differences in plant dry weight or height could be expected. This was confirmed by data analysis which also showed no significant differences in dry weight or height due to tillage treatments—even when separate analyses were made for the three treatments common for four stations and for the four treatments (conventional tillage included) common for all stations but Las Cruces.

Chisel-resistance energy per unit distance. Chisel resistance force (energy per unit distance) was measured at all but the Marana station in 1971. For the three tillage treatments common to the three stations there were no significant differences due to tillage treatments applied. The average chisel resistance (for these three treatments) at Shafter, 3037 ft-lb/ft was, however, significantly lower than the average values at Las Cruces and Safford (4890 and 4685 ft lb/ft, respectively). When data from Las Cruces and Shafter were analyzed (to include effects of the rotary tillage treatment) there were also no significant differences due to treatments. However, when data from Shafter and Safford were analyzed (to include effects of the conventional tillage treatment), it was found that the conventional tillage treatment had a significantly higher chisel-resistance force than the other treatments at Shafter, and a significantly lower chisel resistance force than the other treatments at Safford (see table 17).

Thus, chisel-resistance energy per unit distance and the accumulated effects of the different tillage treatments were not related. Chisel-resistance variability was related more to the intrinsic soil characteristics that varied from zone to zone in a given field than to the changes in the soil induced by the tillage treatment. These zones are illustrated in figure 9, which shows lines of equal chisel resistance for the entire portion of the Safford Experiment Station devoted to this experiment.

The standard deviations of average chisel resistance values were also analyzed. Magnitudes of these values tended to parallel those of chisel resistance. For the three treatments common to the three

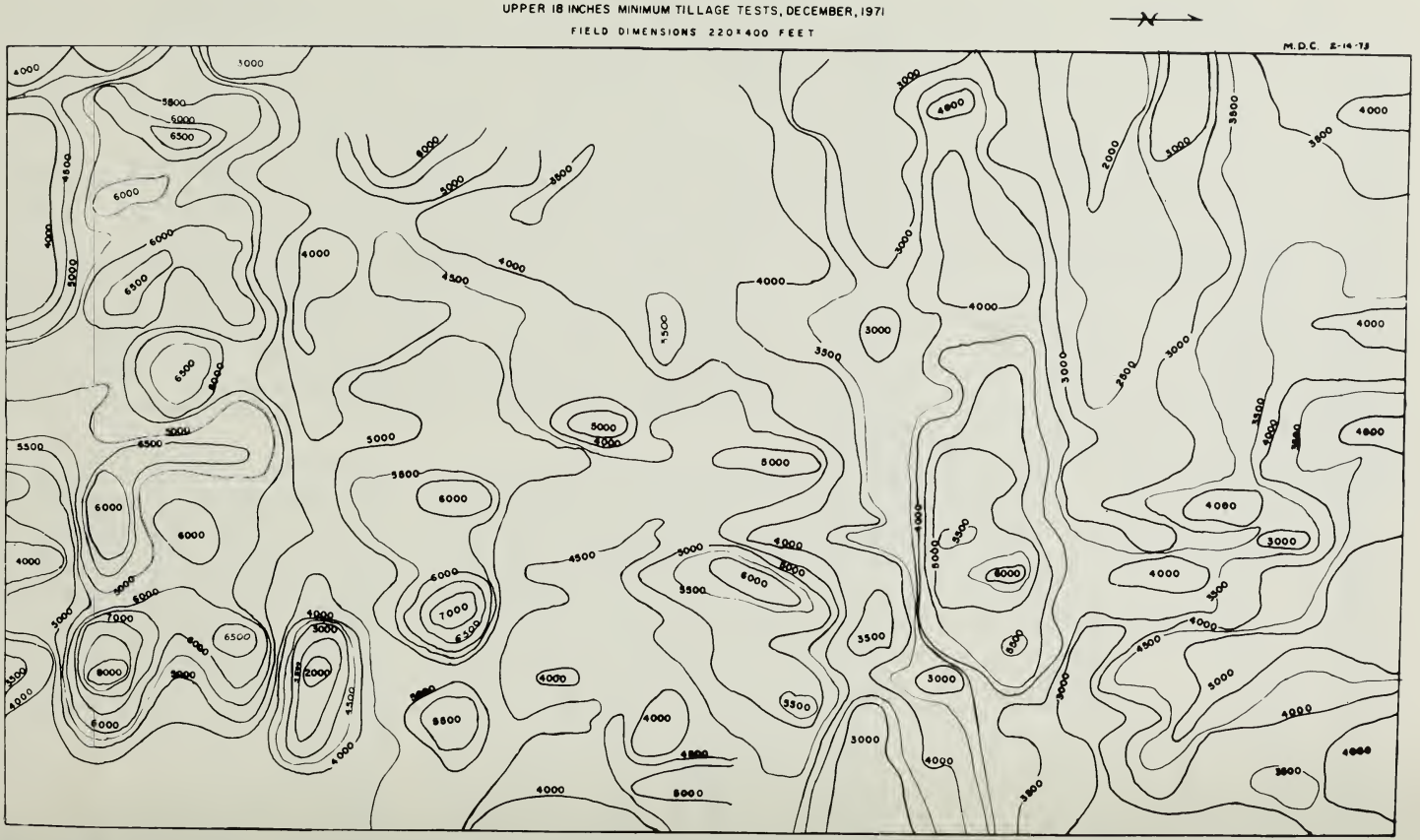

Fig. 9. Map of the portion of Safford Experiment Station devoted to the cotton tillage experiment (1971). Contour lines connect points requiring equal energy inputs per unit of travel for the instrumented chisels shown in figure 5.

TABLE 18
AVERAGE WATER INFILTRATION RATE IN TRAFFIC AND NONTRAFFIC ROWS AT TWO STATIONS
(1971)

Station	Av. water infiltration rate* (inches/hour) in:		Average
	Traffic furrow	Nontraffic furrow	
Las Cruces	0.0261 a a	0.0417 a a	0.0339 b
Shafter	0.454 b a	0.718 b b	0.585 a
Average	0.240 b	0.380 a	0.3098

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

stations, the chisel-list (beds moved) treatment had a significantly lower standard deviation than that of the minimum tillage treatment (551 vs. 732 ft-lb/ft). The standard deviation at Shafter was significantly lower than that at either Las Cruces or Safford stations (442 vs. 665 or 767 ft-lb/ft, respectively).

Water infiltration rate. Water infiltration was measured only at the Shafter (in 1968 and 1971) and Las Cruces (in 1968, 1969, 1970, and 1971) stations. Combined data analysis was made only for 1971 data which were obtained in both traffic and nontraffic furrows. At Las Cruces, traffic was confined to alternate furrows during all cultural operations except harvesting; at Shafter, alternate furrow traffic was maintained even through the harvesting operation.

Table 18 shows that the water infiltration rate at Las Cruces was significantly lower (by nearly 20 times) than at Shafter. This was believed to be a major factor connected with differences in yield and penetration resistance found at Las Cruces as compared with these measures at other stations.

Table 18 also shows that the infiltration rate at Shafter was significantly higher (about twice) in the nontraffic furrow than in the traffic furrow. A similar relationship was found at Las Cruces, but the difference was not significant (table 18).

Comparison of 1971 infiltration rates at the two stations for the chisel-list treatments and the minimum and rotary tillage treatments, showed no significant differences due to the tillage treatments applied. This same relationship prevailed over the four-year period at Las Cruces except for the traffic furrow measurements in 1971. Here, the infiltration rates associated with the chisel-list treatments were approximately half those found for the minimum and rotary tillage treatments.

Seedling emergence. Analyses of seedling emergence data were conducted for all but the Shafter station for 1970 and 1971. Significantly lower plant stands were found in 1971 than in 1970 at all but the Safford station, where there was no significant difference from one year to another. This pattern of results parallels that of yields found for these three stations in the same two years (table 19).

At Las Cruces, seedling emergence for the minimum tillage treatment was significantly lower than for this same treatment at the other two stations. Also at Las Cruces, the chisel-list (beds moved)

TABLE 19

AVERAGE SEEDLING EMERGENCE AT THREE STATIONS WITH THREE TILLAGE TREATMENTS
(1970—1971)

Station	Av. seedlings emerged* (thousands/acre): Minimum tillage	Chisel-list (beds not moved)	Chisel-list (beds moved)	Average
Las Cruces	28.2 b a	32.8 b a	40.7 a b	33.8 a
Safford	46.2 a a	42.6 ab a	46.5 a a	45.1 b
Marana	50.4 a a	47.8 a a	44.2 a a	47.4 b
Average	41.6 a	41.0 a	43.8 a	42.1

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

treatment had significantly higher seedling emergence than for the other two treatments at this station (table 19). Other than these two exceptions, there were no significant differences in seedling emergence found to be due to the three common tillage treatments. This pattern of results parallels the pattern of yield results (table 6), except that at Las Cruces, the yield of the minimum tillage treatment was significantly lower than that of the chisel-list (beds not moved) treatment as well (table 6).

Generally, at Las Cruces over the four-year period (in which rotary tillage treatment data were included), and at Safford

TABLE 20

SOIL DRY-BULK DENSITIES IN TRAFFIC AND NONTRAFFIC FURROWS WITH FOUR TILLAGE TREATMENTS
(SHAFTER STATION, 1971)

Tillage treatment	Soil dry-bulk density (gm/cm^3) in:* Traffic furrow†	Nontraffic furrow†	Average
Minimum tillage	1.68 ab a	1.57 bc b	1.62 ab
Conventional tillage	1.65 ab a	1.65 c a	1.65 b
Rotary tillage	1.65 ab a	1.43 a b	1.54 a
Chisel-list (beds not moved)	1.75 b a	1.59 bc b	1.67 b
Chisel-list (beds moved)	1.62 a a	1.49 ab b	1.55 a
Average	1.67 a	1.55 b	1.61

* Within a block, values with the same letters *to the right* in the same vertical rows are not significantly different from each other at the 5 per cent level. Values with the same letters *underneath* in the same horizontal rows are not significantly different from each other at the 5 per cent level.

† Measurements made 0 to 12 inches deep.

and Marana in 1970 and 1971 (where the conventional tillage treatment data were included), there were no significant differences in seedling emergence due to tillage treatments.

Certain measurements made at individual stations

Shafter. In 1971, soil dry bulk density to a depth of 12 inches below the surface was significantly higher for the traffic furrow with the chisel-list (beds not moved) treatment than for the chisel-list (beds moved) treatment. For measurements made in the nontraffic furrow, the soil dry-bulk density for the rotary tillage treatment was significantly lower than that for most of the other treatments. The dry bulk density with the conventional tillage treatment was significantly higher than that for most of the other treatments (table 20). Total cotton yields as affected by various tillage treatments in 1971 did not follow the same pattern as did the results of soil dry-bulk density values.

For all treatments except conventional tillage (where there was no significant difference) soil dry-bulk density in the top 12 inches was significantly lower in the nontraffic furrow than in the traffic furrow (table 20).

For soil at depths from 12 to 24 inches there were no significant differences in soil dry bulk density due to the various tillage treatments or between traffic and nontraffic furrow locations.

Marana and Safford. In 1970 and 1971 tap root length was measured, and percentage of abnormal roots was noted. No significant differences in tap root length due to variation of tillage treatment were found. The only significant differences in percentage of abnormal roots due to various tillage treatments occurred at the Safford station during 1971 where the conventional tillage treatment resulted in significantly fewer abnormal roots (17.5 per cent) than did the chisel-list (beds moved) treatment (43.8 per cent abnormal roots). At the Safford station, in 1971 the conventional tillage treatment produced the highest yield, and the chisel-list (beds moved) treatment produced the next-to-lowest yield among all the tillage treatments.

In general, however, variation of tillage treatment did not significantly affect root development.

At both Marana and Safford stations an additional tillage treatment was included. This treatment was the same as the chisel-list (beds not moved) treatment, with the exception that chisel depth was from 12 to 14 inches instead of 18 inches. In 1969, 1970, and 1971 there were no significant differences in yield, and for all the other crop and soil parameters measured in 1970 and 1971 at either station, there were no significant differences between the plots subjected to these two treatments.

The reduced chisel depth could be expected to reduce tillage energy input and consequently reduced production costs. The above results indicate that for the conditions encountered at the Marana and Safford stations, there would be no disadvantage in substituting the more economical, shallow chisel-list method for the conventional chisel-list operation that extends 18 inches deep.

Las Cruces. Seedbed conditions were investigated from 1968 to 1971 along with the tillage treatments to determine their influence on cotton yields. Despite the fact that each treatment was applied to the same plot for four years, no significant differences were found in soil moisture content at planting time, in total salt content, in soil pH, in exchangeable sodium content, or in penetration resistance in the top 3 inches of soil due to tillage treatment. Thus, the effects of tillage treatments on yields found at Las Cruces could not be correlated with these seedbed conditions.

The amount of water that could be applied during the first irrigation of the year was measured. Over the four-year

period, the rotary tillage plots accepted a significantly lower amount of water than did the plots for the other tillage treatments. However, in terms of the total amount of water applied in all irrigations during the crop season, there were no significant differences due to tillage treatment or due to year-to-year fluctuations.

Analyses were made of penetrometer readings to determine the extent of variation of penetration resistance from side to side and from top to bottom in the two-row sampling zone, and how these variations may be related to the tillage treatments. Results for the four-year period indicated that there were no significant differences in these parameters due to tillage treatments. There were highly significant differences due to year-to-year fluctuations with variation of penetrometer resistance with depth showing the greatest response. Here, values were lowest in 1969 and unusually high in 1970 and 1971. In 1970 and 1971, penetration resistance was unusually high, since soil moisture at the greater depths was below field capacity.

A Summary

1. Yield:

a) No significant differences due to tillage treatment, except at the Las Cruces station where the minimum tillage and rotary tillage treatments resulted in lower yields than did the chisel-list treatments.

b) Few differences among the various stations, except at Las Cruces where yields were lower—particularly during 1970 and 1971.

c) Lower at all stations in 1970 than in 1969 and lower in 1971 than in 1970. Trend toward lower yields in successive years was most pronounced at the Las Cruces station.

2. Soil penetration resistance:

a) Significant differences only at the Las Cruces station and with the conventional tillage treatment at the Shafter station.

b) Generally, significant increases in penetration resistance corresponded with decreases in yield, although the proportional differences in penetration resistance were of much greater magnitude than the associated differences in yield. The negative correlation between these two factors was found to be significant only at the Las Cruces station, while the inverse relationship was found to be significant at the Safford station, indicating that a generalized relationship cannot be accurately applied to all locations.

c) High penetration resistances and low yields appeared characteristic of minimum tillage and rotary tillage treatments at Las Cruces and for the conventional tillage treatment at Shafter.

3. Standard deviation of soil penetration resistance:

a) Major differences in the standard deviation related to soil differences between stations and soil condition differences from year to year.

b) Chisel-list treatments, despite their concentration of tillage action at 40-inch intervals, tended to result in lower standard deviation values than did other tillage treatments—indicating that chisel-list treatments produced soil conditions for which penetration resistance was more uniform throughout the rooting zone.

4. Development of crop plants:

a) No significant differences due to the various tillage treatments.

5. Chisel-resistance energy per unit distance:

a) No general relationship between

chisel resistance energy per unit distance and accumulated effects of the different tillage treatments.

6. Water infiltration rate:

a) Significantly lower (by nearly twenty times) at the Las Cruces station than at the Shafter station. Considered a major influence on differences in yield and penetration resistance at Las Cruces.

b) Tended to be higher in nontraffic furrows than in traffic furrows.

7. Seedling emergence:

a) No significant differences due to tillage treatments at Las Cruces over the four-year period (in which rotary tillage treatment data were included) and at Safford and Marana in 1970 and 1971 (where the conventional tillage treatment data were included).

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